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## **EMPHASIS™/Nevada CABANA User Guide Version 2.1.1**

C. David Turner, William J. Bohnhoff, Jennifer L. Powell

Prepared by  
Sandia National Laboratories  
Albuquerque, New Mexico 87185 and Livermore, California 94550

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# **EMPHASIS™/Nevada CABANA User Guide Version 2.1.1**

C. David Turner  
Electromagnetics and Plasma Physics Analysis

William J. Bohnhoff  
Jennifer L. Powell  
Radiation Transport

Sandia National Laboratories  
P.O. Box 5800  
Albuquerque, New Mexico 87185

## **Abstract**

The CABLE ANALYSIS (CABANA) portion of the EMPHASIS™ suite is designed specifically for the simulation of cable SGEMP. The code can be used to evaluate the response of a specific cable design to threat or to compare and minimize the relative response of difference designs. This document provides user-specific information to facilitate the application of the code to cables of interest.

## **Acknowledgement**

The authors would like to thank all of those individuals who have helped to bring CABANA to the point it is today, including Gary Scrivner and Wesley Fan for many useful theory and design discussions.

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## Introduction

EMPHASIS™/Nevada CABLE ANALYSIS (CABANA) [1] solves the electrical portion of a cable system-generated electromagnetic pulse (SGEMP) simulation. It takes specific results from the deterministic radiation-transport code SCEPTRE [2] as sources and computes the resulting electrical response to an arbitrary cable load. The cable geometry itself is also arbitrary and is limited only by the patience of the user in meshing and by the available computing resources for the solution. The CABANA simulation involves solution of the quasi-static Maxwell equations using finite-element method (FEM) techniques [1].

The CABANA sources required from SCEPTRE are:

- 1) CHARGE\_OFF\_CONDUCTORS, the net charge knocked off each cable internal conductor (supplied implicitly by SCEPTRE),
- 2) CHARGE deposited into each finite element, and
- 3) ENERGY\_DEPOSITION at each element node

These data are written to the SCEPTRE output in EXODUSII [3] format suitable for reading into CABANA. Since CABANA is written in MKS units, it expects the SCEPTRE results in units of Coulomb(C)/m for both CHARGE\_OFF\_CONDUCTORS and CHARGE. The units of ENERGY\_DEPOSITION are expected to be Rads (dielectric).

The sources produced by SCEPTRE for CABANA are not time dependent. Instead, they represent the total integrated values over the specified radiation pulse. CABANA applies the time dependence to the simulation by assuring, for example, that the total charge in a given element is applied over the specified pulse shape.

## Cable SGEMP Simulation Process

The cable SGEMP simulation process is shown in Fig. 1. The cable must first be modeled and meshed with using 2D or 3D-periodic unstructured elements suitable for SCEPTRE and CABANA. This is an involved process and is described in the original CEPTRE user guide [4]. These two types of elements are associated with the two CABANA simulation modes: 2.5D-mode for 2D cable cross section structures and 3D-mode for 3D-periodic cable structures. Examples of 3D-periodic structures are twisted-shielded pair or cables with braided cable shields where the shield breaks can be modeled as approximately periodic.

The critical aspects of the mesh for CABANA are that boundaries are described by EXODUSII sidesets (either single- or double-sided) and that the elements are 2<sup>nd</sup> order, utilizing quadratic shape functions. This is required to obtain sufficient accuracy in the computation of electric field. The elements can be either 6-node triangles or 8-node

quadrilaterals in 2D and 20-node hexahedra in 3D. The elements should also be reasonably well shaped. Quadrilaterals with aspect ratios of up to approximately 80 can be handled, but expect run times to increase dramatically as the matrix becomes more ill-conditioned requiring significantly more iterations to converge to the required solution tolerance.

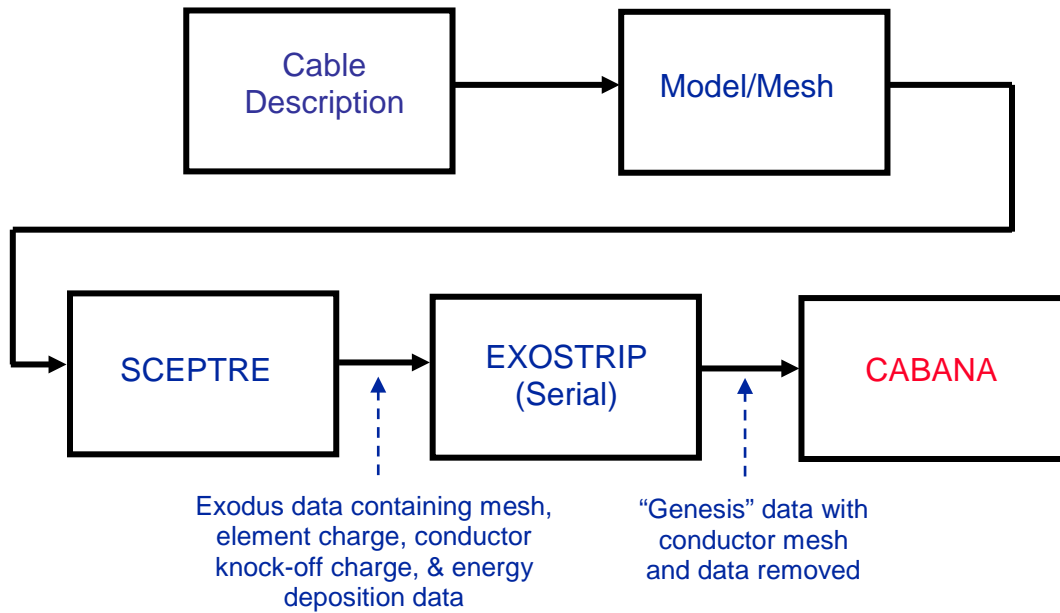


Figure 1. Cable-SGEMP Simulation Process.

After SCEPTRE solves the radiation-transport problem, the data for CABANA are written into an EXODUSII results file. Since SCEPTRE is required to mesh the cable conductors but CABANA has no need for this mesh, it is removed along with the associated data using the EXOSTRIP utility (see Appendix C), which creates a “Genesis” file for CABANA. “Genesis” normally describes a mesh description file in EXODUSII format containing mesh only, no data, thus the quotation marks. This “Genesis” file, along with a CABANA input file is all that is required for a CABANA simulation. During this process, EXOSTRIP also converts the mesh coordinates from cm to m for CABANA.

## CABANA Results

The desired result from a CABANA simulation is normally the current delivered to the cable load(s). This is provided in HISPLT format under the name “LOAD-CURRENT” for a cable with a single inner conductor in units of Amps. For a cable with multiple inner conductors, the name is “LOAD-CURRENT-X” where “X” runs from 0 to N-1 where N is the number of inner conductors. The order of these load current results in the HISPLT file is determined by the order that the cable conductors are defined in the input file using the **conductor** keyword described in a later section.

Additionally, a running integral of all load currents is computed and dumped at the end of the simulation as “Conductor # Load Charge= *value*”, where in this case the “Conductor #” is the sideset id identified with the conductor on the **conductor** keyword line for that conductor.

Also monitored is the maximum global electric field magnitude throughout the simulation and is reported at the end of the simulation as “Global Max Magnitude Electric Field = *value*”.

If requested, additional results such as POTENTIAL, ELECTRIC-FIELD, CHARGE-DENSITY, and CONDUCTIVITY are dumped in the EXODUSII results file. A discussion of CABANA output units and their relationship to the SCEPTRE simulation is presented in Appendix A.

## CABANA Input File and Keywords

The CABANA input uses the standard NEVADA input file format, which includes keywords for debugging, physics type, solver control, output control, and more. Details of all of these except for the specific physics can be found in the ALEGRA/NEVADA users guide [5]. A complete input file for one of the CABANA regression problems is given in Appendix B.

The format for specifying cable System Generated ElectroMagnetic Pulse (SGEMP) physics (i.e., CABANA) and associated keywords is shown in Fig. 2. The keyword “**cable sgemp**” specifies CABANA physics to the code. Most of the remaining keywords are specific to CABANA and are described below.

For verification purposes, another keyword exists for CABANA physics: “**cable sgemp verification, verify *int***”. This keyword instantiates a different CABANA object and is NOT used for normal cable simulations. The **verify** parameter specifies a particular analytic solution to be computed for comparison to the verification simulation.

For a single Poisson solution, the keyword “**cabana poisson**” instantiates another type of CABANA object for this purpose only. See the **Poisson solution keywords** section.

```

cable sgemp
  pulse shape, triangle, risetime 1.e-8, end
  initial time step, 5.e-10, end
  spice model, build
  number sections, 3, end
  section params, sec 1, len .1, exp, no
  section params, sec 2, len .45, exp, yes
  section params, sec 3, len .45, exp, yes
  default section length, .1
  load charge density, no
  load transport charge density, yes
  load dose, yes
  conductor, sideset 1, potential 1., rinpt 1.e8, rload 50.
  shield, sideset 21, potential 0.

block 1
  material 1
end

block 2
  material 1
end

gradual startup factor 1.0
maximum time step ratio 1.2
end

```

Figure 2. Typical CABANA physics keywords.

## Time / time history keywords

### pulse shape

Specifies the time history of the radiation pulse

**pulse shape**, *type*, [*parameter real*], [*parameter real*], **end**

Options for *type* and *parameter(s)* are:

**steady\_state**, **end**

Unity for all time, useful primarily for verification

**triangle**, **risetime** *real*, [**falltime** *real*], **end**

If **risetime** only is given, rises linearly from zero to 1/**risetime** at  $t = \text{risetime}$ , in seconds (s), then falls linearly to zero at time  $2 \times \text{risetime}$ . If **risetime** and **falltime** are given, rises linearly from zero to  $2/(\text{risetime} + \text{falltime})$  at  $t = \text{risetime}$  (s), then falls linearly to zero at time **risetime** + **falltime**. Both have unit integrals.

**square, width *real*, end**

Amplitude  $1/\text{width}$  at  $t = 0$ , remains constant until  $t = \text{width}$  (s), jumps back to amplitude zero (integral is unity)

**sin\_squared, width *real*, end**

$$\frac{2}{\text{width}} \sin^2 \left( \frac{\pi t}{\text{width}} \right) \quad 0 < t < \text{width},$$

zero otherwise (integral is unity)

**exponential\_pulse, alpha *real*, end**

$$\frac{1}{\alpha} e^{-\frac{t}{\alpha}} \quad (\text{integral is unity})$$

**double\_exponential\_pulse, alpha *real*, beta *real*, end**

$$\frac{1}{\alpha - \beta} \left( e^{-\frac{t}{\alpha}} - e^{-\frac{t}{\beta}} \right) \quad (\text{integral is unity})$$

**initial time step**

Specifies the beginning time step (s) for the simulation

**initial time step, *real*, [gamma dot ratio *real*], [time step scale *real*], end**

**Gamma dot ratio** and **time step scale** are optional parameters which, if included, will cause the time step to change to **initial time step \* time step scale** after the **pulse shape** function falls below **pulse\_shape\_max \* gamma\_dot\_ratio**, where **pulse\_shape\_max** is computed during the simulation. Typical values for **gamma dot ratio** and **time step scale** are 0.1 and 5.0, respectively. If these optional parameters are not included, the time step will remain constant at **initial time step** for the entire simulation.

## Radiation-incidence keyword

By default, CABANA applies the cable excitation as if it were planar, normally incident broadside to the cable sections. In this case, all cable sections are excited simultaneously. The following keyword can be used to change the angle of incidence as shown in Fig. 3 for a three-section cable. Here, the cable-section excitations are staggered by the appropriate retarded time based on the timing at the section *centers*. The user should keep in mind also that the “load” end of the cable is the end on the right in Fig. 3. Therefore, if it is desired to have the excitation plane strike the load-end first, the angle should be

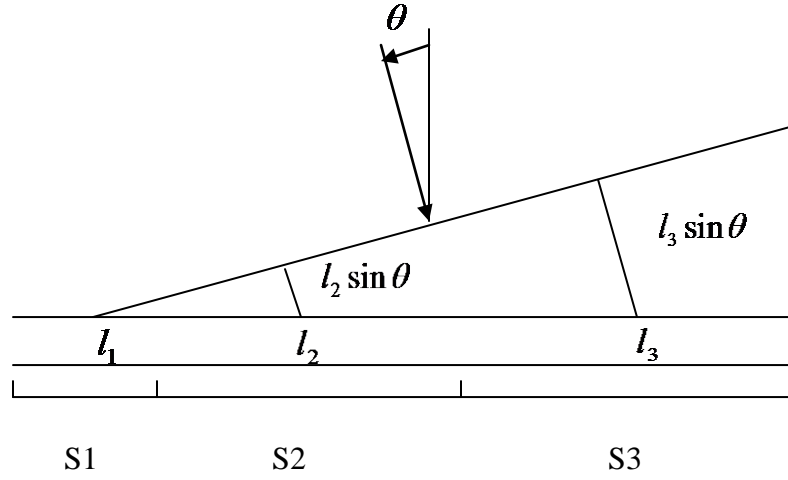
negative. Also in Fig. 3,  $l_0$  is the cable origin, either the left end (for  $\theta$  positive) or the right end (for  $\theta$  negative).

#### nonnormal incidence

Specifies non-normal planar incidence with angle  $\theta$  from normal.

#### nonnormal incidence, angle *real*

The **angle** is the angle  $\theta$  in Fig. 3, where  $-90 < \theta < 90$ .



$$\text{Section1: } f\left(t - \frac{(l_1 - l_0) \sin \theta}{c}\right)$$

$$\text{Section2: } f\left(t - \frac{(l_2 - l_0) \sin \theta}{c}\right)$$

$$\text{Section3: } f\left(t - \frac{(l_3 - l_0) \sin \theta}{c}\right)$$

Figure 3. Non-normal incidence.

## SPICE control keywords

### spice model

Specifies how SPICE is utilized and the origin of the spice model deck for the simulation

#### spice model, *spice\_option*

Options for *spice\_option* are:

**NO**

SPICE not used in simulation

**USE**

Lumped-parameter SPICE deck will be read from file

**BUILD**

Lumped-parameter SPICE deck will be created and written to a file during startup

Generally, the initial simulation for a given cable geometry is accomplished using the **BUILD** option which writes the SPICE deck to a file (see **spice file** keyword below). If custom changes are desired to this SPICE model for subsequent simulations, the file can be edited and the **USE** option invoked thereafter. See Appendix D.

**spice file**

Specifies the filename from which to read the SPICE model deck if “**spice model**, **USE**” is specified or the file to which to write the SPICE deck if “**spice model**, **BUILD**” is specified.

**spice file**, “*filename*”

*filename* is an ascii string and the quotes are required. If **spice file** is not specified, the SPICE deck is either read from or written to the default filename *problem\_name.in*. Note that this file, either the default or that specified by **spice file**, will be OVERWRITTEN for the next simulation if it is left in place on the file system.

**spice step fraction**

Specifies the fraction of the initial time step (see **initial time step** keyword) which SPICE will use as a maximum internal time step.

**spice step fraction**, *real*

The default is 0.1. In some cases, it is necessary to increase this value to something like 0.5 to allow SPICE to converge correctly. If such a SPICE error occurs, the error is trapped and the user is notified to modify this value.

**Section keywords****number sections**

Specifies the number of sections to divide the cable length into for a 2.5D simulation and optionally specifies the lengths of each section. However, for a large number of sections, the line length may exceed the maximum. In this case, use multiple of the below **section params** keywords.

**number sections**, *int*, [**sec** *int*, **len** *real*], [**sec** *int*, **len** *real*], [...], **end**

Each [**sec** *int*, **len** *real*] specifies the section number and length, in meters (m), of one of the sections. If a section is not specified, its' length is defined by the **default section length** keyword below. In addition, it will be exposed to radiation by default (see **section params** below).

#### **section params**

Optionally specifies the lengths of each section and whether the section is exposed to radiation. The length parameter can be specified with the **number sections** keyword above if desired.

**section params**, **sec**[*tion*] *int*, **len**[*gth*] *real*, **exp**[*osed*], *bool*

Each keyword of this type specifies the section number and length (m) of one section. Options for the exp parameter are “**YES**” (or “**TRUE**”) and “**NO**” (or “**FALSE**”). Note that the comma after **exp** must be present. If a section is not specified, its' length is defined by the **default section length** keyword below and **exp** is “**YES**”.

#### **default section length**

Specifies the default length (m) of each cable section

**default section length**, *real*

#### **multisection map**

Optionally specifies the mapping of auxiliary radiation-transport results to cable sections for multi-section excitation

**multisection map**, **radtrans\_file** “*filename*”, **section\_index** *int*, [...], **end**

Lines of the above form are repeated for each auxiliary SCEPTRE simulation results file. Note that the use of this keyword is OPTIONAL. If no multisection map is specified, the default map is used: SCEPTRE data stored in the simulation Genesis file is applied to ALL SECTIONS in the cable. The required parameters are:

**radtrans\_file**: *filename* is an ASCII string for the name of a SCEPTRE results (.exo) file

**section\_index** (or shortened to **section**): an integer value in the range 1 thru **number sections** specifying each section the specified



SCEPTRE results (*filename*) will be applied to. Additional **section**, *int* combinations can be added before the **end** specifying other sections to receive data from this *filename*.

## SCEPTRE data keywords

### **load charge density**

Specifies whether the SCEPTRE data for CHARGE density contained in the simulation Genesis file is loaded before the first time cycle

#### **load charge density, *option***

Options for *option* are:

##### **NO** (default)

CHARGE not loaded up front, typical for actual cable simulation

##### **YES**

CHARGE loaded up front, typical for verification simulation

### **load transport charge density**

Specifies whether SCEPTRE data for CHARGE density contained in the simulation Genesis file is prepared for loading into the simulation over the radiation pulse defined by **pulse shape**

#### **load transport charge density, *option***

Options for *option* are:

##### **YES** (default)

CHARGE prepared for loading, typical for actual cable simulation

##### **NO**

CHARGE not prepared for loading, typical for verification simulation

### **load dose**

Specifies whether SCEPTRE data for ENERGY\_DEPOSITION contained in the simulation Genesis file is prepared for loading into the simulation over the radiation pulse defined by **pulse shape**

#### **load dose, *option***

Options for *option* are:

**YES** (default)

ENERGY\_DEPOSITION prepared for loading, typical for actual cable simulation

**NO**

ENERGY\_DEPOSITION not prepared for loading, typical for verification simulation or for turning off radiation induced conductivity (RIC)

### **load conductor current**

Specifies whether the SCEPTRE data for knock-off charge from each cable **conductor**, contained in the simulation Genesis file, is prepared for loading into the simulation over the radiation pulse defined by **pulse shape**

**load conductor current**, *option*

Options for *option* are:

**YES** (default)

CONDUCTOR CHARGE prepared for loading, typical for actual cable simulation

**NO**

CONDUCTOR CHARGE not prepared for loading, typical for verification simulation

## **Cable topology keywords**

### **conductor**

Specifies each internal cable conductor

**conductor**, **sideset** *int*, [**sideset** *int*, ...], **potential** *real*, **rinpt** *real*, **rload** *real*

Each internal cable conductor is specified with one of these keyword lines.  
The required parameters are:

**sideset**: Specifies one (or more) sideset id(s) in the Genesis file defining this conductor

**potential:** Specifies the initial potential, in volts (V), of the conductor (applies only to verification simulations, ignored for actual cable simulations)

Optional parameters are:

**rinpt:** Specifies the resistance (ohms) to be applied to the “input” (often floating) end of the SPICE model.

**rload:** Specifies the resistance (ohms) to be applied to the “load” end of the SPICE model. It is through **rload** that the main CABANA output, LOAD-CURRENT in the HISPLT file, flows.

If the optional cable loads are not specified, the defaults are **rinpt**=1.e8 ohms and **rload**=50 ohms. The user should keep in mind that although **rinpt** can be anything, it is only the current through **rload** which is monitored and output to the HISPLT file.

## interface

Specifies each interface between dielectrics of differing conductivity properties

**interface**, **sideset** *int*, [**sideset** *int*, ...], **initial charge density** *real*

Each cable dielectric interface is specified with one of these keyword lines. The required parameters are:

**sideset:** Specifies one (or more) sideset id(s) in the Genesis file defining this interface

**initial charge density:** Specifies the initial charge density (C/m) on the interface before the simulation begins (normally zero for cable simulations)

## shield

Specifies the cable shield

**shield**, **sideset** *int*, [**sideset** *int*, ...], **potential** *real*

The required parameters are:

**sideset:** Specifies one (or more) sideset id(s) in the Genesis file defining the shield

**potential:** Specifies the shield potential (V) for the simulation, normally zero for cable simulations

The user is responsible for properly defining a conductor, interface, or shield with the correct number of sidesets. CABANA has no way of knowing that a portion of the boundary for say, a conductor, has been left out.

The sidesets defining these boundary entities may be either single or double sided. In practice, the proper use of the EXOSTRIP utility guarantees that only an interface can have a double-sided sideset definition.

### **symmetry**

Specifies quarter or half mesh symmetry. A correction is applied to compute the correct response for the full problem.

**symmetry, type**

Options for *type* are:

**none** (default)  
No symmetry

**quarter**  
Two symmetry planes

**half**  
One symmetry plane

## **Shockley method keyword**

### **shockley method**

Specifies the use of the simple Shockley integral method [6]. This method removes the requirement for  $\mu m$ -scale meshing for SCEPTRE near the interfaces and provides faster convergence as well. However, RIC must be ignored since it cannot be modeled with this formulation. SCEPTRE must now provide a current density rather than a charge density. This current density is integrated against the computed “Green’s function” solutions using the following:

$$R = - \int_V \bar{E} \bullet \bar{J} dv$$

If this method is specified the other SCEPTRE data keywords are overridden to “no”. Plot data is not available for CHARGE\_DENSITY, POTENTIAL, or ELECTRIC\_FIELD and should not be specified. Requesting TRANSPORT\_CURRENT for plot data will provide the time history and spatial distribution of the source current density.

**shockley method**, *option*

Options for *option* are:

**NO** (default)

Use standard full-simulation method

**YES**

Use Shockley method and override everything else

## Charge relaxation keyword

### **enforce relaxation limit**

If conductivity is present, this keyword specifies whether an error is issued and the simulation halted in the case that an element relaxation time is too short relative to the time step chosen. Here the element relaxation time is defined as *permittivity/conductivity*. Based on convergence verification tests, it has been determined that good results are obtained as long as the element relaxation time is less than twice the time step. In other words, as long as there are at least two time samples per relaxation time.

**enforce relaxation limit**, *option1* [, **print warning**, *option2*]

Options for **enforce relaxation limit** are:

**YES** (default)

Fatal error is issued and the simulation halted with information about the shortest elemental relaxation time

**NO**

Simulation continues with or without warning

If **enforce relaxation limit** is *yes*, **print warning** is irrelevant. Otherwise, the options for **print warning** are:

**YES**

Simulation continues with warning printed containing the shortest elemental relaxation time

**NO** (default)

Simulation continues without warning

## **Box/Cavity SGEMP Drive inclusion keywords**

Current sources can be included in the simulation to accommodate the forward coupling of box and cavity SGEMP drives during the cable simulation for a cable with a single inner conductor. These sources (one for box drive and/or one for cavity drive) are automatically inserted into the SPICE deck across the **rinpt** end of the conductor, as described by the **conductor** keyword. Typically, the drive is provided through a tabular **function** of samples from a box or cavity SGEMP simulation but it can be provided by one of the functional forms of the **function** keyword as well.

### **box drive**

Specifies that a box-drive current source be created in the SPICE deck and that it be driven with the supplied function.

**box drive, function** *int*, [**scale** *real* **shift** *real*]

The tabular function can be scaled or shifted in time as necessary.

### **cav drive**

Specifies that a cavity-drive current source be created in the SPICE deck and that it be driven with the supplied function.

**cav drive, function** *int*, [**scale** *real* **shift** *real*]

The tabular function can be scaled or shifted in time as necessary.

## **Poisson solution keywords**

### **Poisson solution**

Specifies a single Poisson solution and exit

**Poisson solution, charge density** *real*, **results file** “*filename*”

The required parameters are:

**charge density**: Specifies a uniform charge density ( $C/m^2$ ) in the elements

**results file**: ASCII file to which the resulting element electric fields are written

The boundary conditions for the solution are specified using the conductor keyword above.

### **export results**

Specifies that the resulting element electric fields are to be exported for a subsequent 3D **UTDEM** simulation

**export results, genesis file** “*filename*”, **sideset** *int*

The required parameters are:

**genesis file**: 3D Genesis file for results export

**sideset**: Sideset in Genesis file to store results with

This Genesis file and sideset must be the same used to generate the 2D mesh for the Poisson solution in the first place using the **UTDEM Sideset Extractor** physics option in EMPHASIS™.

The Poisson solution requires the framework keyword **termination cycle = 1** to be specified. This ends the simulation after a single solve as desired.

### **Single-cycle solution**

If RIC is not important and the time history of the response is not required, it is possible to compute the total charge transferred to the load with a single computation cycle. This is accomplished by setting the following keywords:

**spice model**, no  
**number sections**, 1, end  
**default section length**, *length*  
**load charge density**, yes

**load conductor current**, yes  
**load transport charge density**, no  
**load dose**, no  
**termination cycle** = 1

After a single cycle, the response is computed from the conductor knock-off charge and the rho-induced charge on the conductor as follows:

$$R = q_{ko} - q_i$$

### Framework-related keywords within the physics block

These keywords are really framework keywords [5] and must be placed within the physics definition keyword block.

#### **block**

Define a finite-element block

**block** *int* **material** *int*

Relates the mesh block id **block** to material definition **material**

#### **function**

Define a user-defined function for use by the **box/cavity drive** keywords

**function** *int*  
    *time0* *value0*  
    *time1* *value1*  
    *time2* *value2*  
    .  
    .  
    .  
**end**

#### **gradual startup factor**

Factor by which the initial time step is multiplied, default is 0.01

**gradual startup factor** *real*



Gradually increases the initial time step. For CABANA, the value is normally set to 1.0.

### **maximum time step ratio**

Maximum ratio by which a time step may grow in a given cycle

**maximum time step ratio** *real*

Gradually increases the time step from the old to the new value. This effects CABANA when **time step scale** > 1.0 on the **initial time step** line.

## **Framework Keywords**

These keywords are framework keywords [5] which are required for a successful CABANA simulation.

### **Material-related keywords**

#### **material**

Define a material model for a material

```
material int
      model int
      model int
      ...
end
```

Relates the material **material** to material model(s). For CABANA only one model applies to each material.

#### **model**

Define a material model

```
model int string
      [parameter real]
      [parameter real]
      ...
end
```

Relates the material model **model** to a specific model name defined by the name *string*.

Options for *string* and *parameter*(s) are:

```

RIC Electrical
    eps real
    mu real
    sigma0 real
    coefficient real
    exponent real
end
or
HP Gas Electrical
    eps real
    mu real
    sigma0 real
    density real
    water_fraction real
end

```

where **eps** is the relative permittivity of the medium, **mu** is the relative permeability of the medium, and **sigma0** is the initial or dark conductivity (Mho/m) of the material.

The radiation-induced conductivity (RIC) model [7] takes the following form:

$$\sigma = \sigma_0 + \varepsilon K \dot{\gamma}^e$$

where  $\sigma$  is the conductivity in Mho/m,  $\sigma_0$  is the dark conductivity in Mho/m,  $\varepsilon$  is the permittivity in Farad(F)/m,  $K$  (**coefficient**) is in ((Mho/F)/(Rad/s)),  $\dot{\gamma}$  is the dose rate in Rad/s, and  $e$  is the **exponent** parameter. Typical values for kapton are  $\varepsilon = 3.5\varepsilon_0$ ,  $K = 3.23 \times 10^{-6}$ , and  $e = 0.95$ .

The high-pressure (HP) gas model is described in [8][9]. The independent variables in the model are **density** (kg/m<sup>3</sup>) and **water\_fraction**, nominally 1.23 and 0.02, respectively.

Example input file fragments for these model specifications are shown in Fig. 4.

```

Model 1 RIC Electrical
    eps 2.
    mu 1.
    sigma0 1.e-3
    coefficient 3.23e-6
    exponent 0.95
end

Model 2 HP Gas Electrical

```

```

eps 2.
mu 1.
sigma0 0.
density 1.23
water_fraction 0.02
end

```

Figure 4. Typical material model descriptions.

## Simulation time and output control keywords

Typical simulation time and output control keywords are shown in Fig. 5.

**termination time** = *real*

Total time (s) for which to run the simulation

**termination cycle** = *int*

Total cycles for which to run the simulation

**emit screen, cycle interval** = *int*

Print status line to standard out every **cycle interval** cycles

**emit plot, cycle interval** = *int*

Write **plot variables** to exodus file every **cycle interval** cycles

**emit hisplot, cycle interval** = *int*

Write global variables to hisplt file every **cycle interval** cycles

**plot variable**

*registered-variable name*

*registered-variable name*

...

**end**

Valid plot variables for CABANA are potential, electric\_field, charge\_density, vis\_face\_charge\_density (interface charge density), econ (conductivity) (from RIC and HP Gas material model), and electron\_concentration, negative\_ion\_concentration, avalanche\_rate, attachment\_rate (from HP Gas material model)

```

termination time = 1.e-8

emit screen, cycle interval = 1
emit plot, cycle interval = 10
emit hisplt, cycle interval = 1
plot variable
  potential
  electric_field

```

```

charge_density
vis_face_charge_density
econ
electron_concentration
end

```

Figure 5. Typical simulation and output control keywords.

If plot variables are not desired the “emit plot” line can be omitted. If plot variables are desired but not at frequent intervals, the cycle interval should be set to large values to avoid exceedingly large exodus files.

### Linear solver keywords

Typical linear solver keywords, in this case for AZTEC [10], are shown in Fig. 6. In this case, conjugate gradient (cg) is specified with no preconditioning but with symmetric diagonal scaling. No output is requested from AZTEC after each solve to a tolerance level of 1.e-9 with a maximum number of cg iterations set to 1000 (default is 500). The “polynomial order” should always be set to “1” for efficiency.

```

aztec
  solver,    cg
  precondition, none
  scaling,   sym_diag
  output,    none
  tol        = 1.e-9
  polynomial order, 1
  max iterations, 1000
end

```

Figure 6. Typical solver control keywords.

## Follow-up Simulations with Stored Charge

It may be desirable to do a series of simulations where the stored charge remaining in the dielectric from previous simulations is used as an initial charge distribution for subsequent simulations. This can be accomplished with CABANA by utilizing the restart capability of the framework. The procedure is as follows:

Add the following restart keywords to the initial input file:

**restart dumps, 1**

**emit restart, cycle interval = *int* OR**

**emit restart, time interval = real**

**read restart dump = -1**

The first indicates that only one restart dump is saved as the simulations progress. The second tells the framework to emit a restart dump either every **cycle interval** cycles or every **time interval** seconds. The third says that upon restart, the framework should read and load data from the latest restart dump available. In the case of the initial simulation of the series, the user should verify that no restart dumps exist in the directory and the simulation will then start at time=0. as desired. Restart dumps are written to files in the format: *problem\_name.dmp.restart\_number*.

For subsequent simulations, the user *must* change the **termination time** to have a later termination time for the next simulation. With this change, the follow-on simulation will begin at the time of the final restart dump from the previous simulation after loading the residual dielectric charge. In addition, the original gen file can be optionally replaced at this time with a new one having the identical mesh description but containing a different set of radiation-transport results. The user is also free to change other simulation parameters such as pulse shape, time step, etc.

A key assumption in this process is that the SPICE circuit model is completely discharged after each simulation in the series, since no SPICE state is saved. This requires that each simulation be run until such time as this is essentially the case, i.e., all cable reflections have subsided and a reasonably steady-state condition has been reached.

## Conclusion

This document, along with the user guides for a modeling and meshing tool such as IDEAS, the radiation-transport code SCEPTRE, and the exodus-file stripping tool EXOSTRIP should allow the user to successfully utilize CABANA to simulate the cable SGEMP response of an arbitrary cable geometry. To gain experience, the CABANA regression suite contains several realistic cable simulations, both 2.5D and 3D. Although these do not have realistic radiation-transport data in their Genesis files, the data does adequately exercise the algorithms in the code and fully demonstrates the cable simulation.

## References

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10. R. S. Tuminaro, M. Heroux, S. A. Hutchinson, J. N. Shadid, *Official Aztec User's Guide Version 2.1*, Sandia National Laboratories Report SAND99-8801J, Nov. 1999.

## Appendix A. CABANA output units

The units associated with the CABANA output depend on the source normalization applied during the SCEPTRE simulation. Assume that the source intensity is  $F$  cal/cm<sup>2</sup> with an average spectral energy of  $E$  MeV/photon. SCEPTRE source normalization multiplies the source intensity  $F$  by

$$\frac{2.61 \times 10^{13} (MeV / cal)}{E (MeV / photon)}$$

yielding the fluence in photon/cm<sup>2</sup>. With this normalization, the load currents from CABANA are in units of Amps (A). Without this normalization, the load currents are in units of A/(photon/cm<sup>2</sup>). Centimeters appear here because SCEPTRE is written in CGS units.

The units of other possible CABANA outputs are V for potential, V/m for electric field, C/m<sup>3</sup> for charge density, and mho/m for conductivity.

Intentionally Left Blank



## Appendix B. Complete CABANA input file

```
$-----BEGIN_QA-----
$ Tags:          cabana physics library
$ CVS: $Id: coax_quad8.inp,v 1.6 2003/01/22 05:32:12 wjbohn Exp $
$-----END_QA-----

$debug modes, LOCATION, FILE, end
$debug modes, LOCATION, FILE, EXODUS, CABANA, end

title
  CABANA: Coax w/coarse quad8 mesh

$$$$$$$$$$$$$$$$ physics options $$$$$$$$$$$$$$$$$$

$ The following two lines should be specified instead of CABLE SGEMP
$ if a verification test is desired rather than a normal simulation
$CABLE SGEMP VERIFICATION
  $VERIFY, 1

CABLE SGEMP
  pulse shape, triangle, risetime 1.e-9, end
  initial time step, 1.e-10, end
  spice model, build
  number sections, 1, end
  default section length, .1
  load charge density, no
  load transport charge density, yes
  load dose, yes
  conductor, sideset 1, potential 1., rinpt 1.e8, rload 50.
  shield, sideset 21, potential 0.

  block 1
    material 1
  end

  block 2
    material 1
  end

  gradual startup factor 1.0
  maximum time step ratio 1.2
end

aztec
  solver,    cg
  precondition, none
  scaling,   sym_diag
  output,    none
  tol        = 1.e-9
  polynomial order, 1
end

units, si
```

```

$$$$$$$$$$$$$$$$$$$$ execution control $$$$$$$$$$$$$$$$$$

termination time = 1.e-8

$$$$$$$$$$$$$$$$$$$$ output control      $$$$$$$$$$$$$$$$$$

emit screen, cycle interval = 1
emit plot, cycle interval = 1
emit hisplt, cycle interval = 1
plot variable
    potential
    electric_field
    charge_density
end

$$$$$$$$$$$$$$$$$$$$ material models $$$$$$$$$$$$$$$$$$

Material 1
    Model 1
end

Model 1 RIC Electrical
    eps 2.
    mu 1.
    sigma0 1.e-3
    coefficient 3.23e-6
    exponent 0.95
end

$ Expect some Aztec "loss of precision" warnings due to
$  low Aztec tolerance
expect 0 errors ? warnings

crt: off
exit

```

## Appendix C. EXOSTRIP User Manual

### Introduction

The EXOSTRIP utility is designed to remove the cable conductor element blocks from a SCEPTRE Exodus output file. SCEPTRE is required to mesh these cable conductors but CABANA does not process this mesh. EXOSTRIP removes the cable conductors along with the associated data and creates a “Genesis” file for CABANA. “Genesis” normally describes a mesh description file in EXODUSII format containing mesh only, no data, thus the quotation marks. Like SCEPTRE, EXOSTRIP exists in the NEVADA framework and running this utility requires a “*runid.inp*” input file and a similarly named SCEPTRE Exodus output file, “*runid.gen*”. Figure C-1 depicts a generic EXOSTRIP input file which should look very familiar to the user as it follows the input file structure of SCEPTRE.

```
$ QA comments

$ Debug modes requested by user
DEBUG MODE: LOCATION $ An Example Debug Mode

$Execution Control Section
Title
    A generic input file for EXOSTRIP

$Exostrip Section
EXOSTRIP

    $ EXOSTRIP Keywords

END $ of the Exostrip

$ Execution Control Specifications
TERMINATION CYCLE 1

$ End of Problem Specifications
EXIT

$ Everything below the EXIT keyword is ignored
```

Figure C-1 Generic EXOSTRIP Input File

### EXOSTRIP Keywords

The EXOSTRIP utility specification is enclosed in the keyword group:

```
EXOSTRIP
    $ EXOSTRIP subkeywords
END
```

There is only one EXOSTRIP keyword group which tells EXOSTRIP what element blocks, node sets and side sets to remove from the Exodus file it is processing.

#### **STRIP EXODUS**

**BLOCK** (*int*),           *\$ list all blocks separated by comma*  
**NODESET** (*int*),       *\$ list all node sets separated by comma*  
**SIDASET** (*int*)       *\$ list all side sets separated by comma*

#### **END**

The **STRIP EXODUS** keyword describes the Exodus entities to strip from the Exodus file. All conductor element blocks to be stripped are identified with the subkeyword **BLOCK** followed by the ID number. All node sets and side sets that are NOT associated with dielectric material in the cable must be stripped as well. The node sets to be stripped are identified with the **NODESET** keyword followed by the node set ID number. Users should note that node sets are not used by CABANA, so EXOSTRIP usually strips ALL node sets from the mesh. The side sets to be stripped are identified with the **SIDASET** subkeyword followed by the side set ID number.

The **CONVERT CAVITY SGEMP DATA** keyword describes which side sets in the Exodus file contain SCEPTRE radiation-transport moment-expansion data describing surface emission angular flux. The number of desired theta (polar angle) and phi (azimuth angle) bins must also be supplied. These data will be converted to PFF format and exported for use by EMPHASIS UTDEM-PIC. The sub keywords can be provided in any order.

#### **CONVERT CAVITY SGEMP DATA**

**SIDASET** (*int int ...*),       *\$ list all side sets to be converted*  
**THETA BINS** (*int*),       *\$ number of theta bins from  $\theta = 0 - \pi/2$*   
**PHI BINS** (*int*)       *\$ number of phi bins from  $\phi = 0 - 2\pi$*

#### **Example EXOSTRIP Input File**

Figure C-2 depicts an example RG402 coaxial cable with the element block, side set and node set ID numbers. The conductors in this cable are element blocks 1 (Copper), 3 (Silver), 4 (Copper) and 5 (Steel). Side sets 1, 4 and 5 are not associated with the dielectric region in element block 2 (Teflon) and need to be removed. All node sets need to be removed for CABANA. The EXOSTRIP input file for this cable is given in Figure C-3.

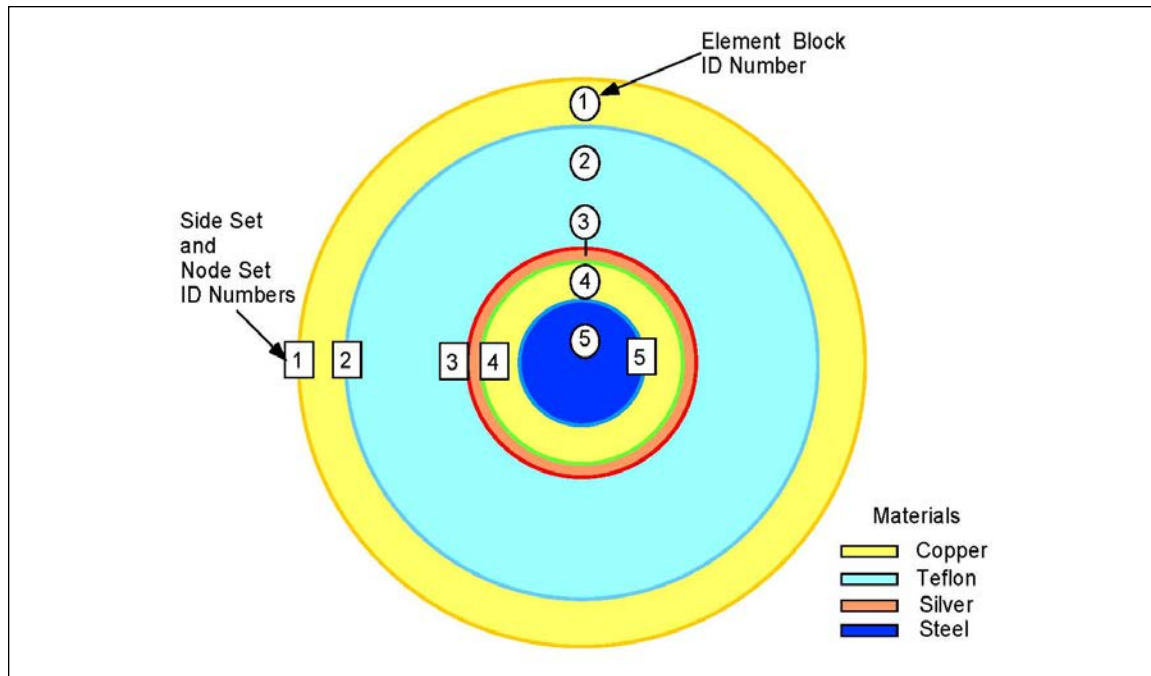


Figure C-2 RG402 Coaxial Cable

```

$-----BEGIN_QA-----
$ RUNID:  rg402
$
$-----END_QA-----

TITLE
  EXOSTRIP: RG402 COAXIAL CABLE EXAMPLE

$$$$$$$$$$$$$$$$ PHYSICS OPTIONS $$$$$$$$$$$$$$$$

EXOSTRIP

  STRIP EXODUS, BLOCK 1, BLOCK 3, BLOCK 4, BLOCK 5,
    NODESET 1, NODESET 4, NODESET 5,
    SIDESET 1, SIDESET 4, SIDESET 5,
  END

END

$$$$$$$$$$$$$$$$ EXECUTION CONTROL $$$$$$$$$$$$$$$$

TERMINATION CYCLE = 1

EXIT

```

Figure C-3 Example EXOSTRIP Input File for RG402 Cable

## Running EXOSTRIP

To run EXOSTRIP use the **Exostrip** script provided with your distribution:

**\$ Exostrip runid**

The stripped “Genesis” file created by EXOSTRIP is written to *runid.Stripped.gen*. For the example in Figure C-3 with a runid of rg402:

**\$ Exostrip rg402**

The command above will create a file named rg402.Stripped.gen. This file becomes the input “Genesis” file for a subsequent CABANA run.

## Appendix D. Modifying the SPICE Deck

As noted in the **SPICE control keywords** section, the **spice model, build** keyword is typically used in an initial simulation to generate the SPICE deck for a cable. For a subsequent simulation, if the user wishes to modify the cable load to something more complicated than the simple resistive load added by the **conductor** keyword then the SPICE deck must be edited manually. For subsequent simulations, the user *must* use the **spice model, use** keyword to have the code read the modified deck. In addition, if the user desires to change the name of the SPICE deck from the default name of *problem\_name.in*, the **spice file, “filename”** keyword must be used to specify the new name.

Modifications to the SPICE deck follow standard SPICE conventions. For example, if a complicated load is to be connected to the cable then the load SPICE circuit description can either be inserted directly into the file, using unique node numbers and device names of course, or a SPICE **.SUBCKT** can be used.

The first step in modifying the file for new load(s) is to determine what nodes the load(s) are connected to. The SPICE deck generation algorithm places resistive loads on each end of each cable conductor. Referring to the **conductor** keyword, the **rinpt** value is placed on the “input” end of the cable and the **rload** value is placed on the “output” end. The “output” end is the “LOAD-CURRENT” which is monitored and output by the code in the *problem\_name.his* file. The SPICE solver simply returns the node voltage across the output “load”, assumed to be a simple resistor. The return value is then divided by the load resistance to determine the load current.

The algorithm used for numbering the loads is as follows. Assume the cable has N conductors divided into M sections. The “input” load on the first conductor (the first **conductor** keyword line in the *problem\_name.inp* file) is R[1]. The “output” load on the first conductor is R[2]. The input load on the second conductor is R[3] and the output load is R[4], etc, down to the final conductor N which has input load R[2N-1] and output load R[2N]. Therefore, for the nth conductor, the input load is R[2n-1] and the output load is R[2n]. Note that the square brackets are used here only for clarity and are not in the actual SPICE deck, *problem\_name.in*.

To determine how to modify the return voltages to provide the desired value, the nodes to which the loads connect must be determined. The automated resistive loads always connect between some floating node and ground, which is always node 0. The input load on the first conductor connects to nodes 1 and 0 and the output between nodes M+2 and 0. On the second conductor, the input load is on node (M+2)+1 and the output load node 2(M+2) down to the final conductor N where the input load is on node (N-1)(M+2)+1 and the output load on node N(M+2). Therefore for the nth conductor, the input load connects to node (n-1)(M+2)+1 and the output load to node n(M+2).

At the end of the SPICE deck, there is a series of **.PRINT TRAN** V(i), V(j), V(k), ... lines. Presently, only the output load voltage, V( n(M+2) ) for each conductor n, is monitored by the code. This voltage is divided by the **rload** value on the appropriate **conductor** keyword line to determine the load current. If this happens to be the desired result across the new load or subcircuit, then nothing need be done in the **.PRINT TRAN** section. To have the code only report the voltage, then change the **rload** value to 1 and remember that the LOAD-CURRENT in the *problem\_name.his* file is actually load voltage.

If it is desired to have the voltage between any two nodes instead, then replace each of the V( n(M+2) )'s, for each conductor n, with something like V(7,5) for example which specifies the voltage between nodes 7 and 5. Again, if the result desired is simply this voltage difference then change the **rload** value to 1 for that conductor.

A SPICE **.SUBCKT** can be used if the voltage or voltage difference desired is on or between the external nodes of the subcircuit. If results are required from inside the subcircuit, then the circuit must be placed into the SPICE deck inline so that the necessary nodes are global. The desired nodes can then be referred to in the **.PRINT TRAN** line(s).



## Distribution

1	MS1152	K. L. Cartwright, 01352
1	MS1152	C. D. Turner, 01352
1	MS1167	E. F. Hartman, 01343
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